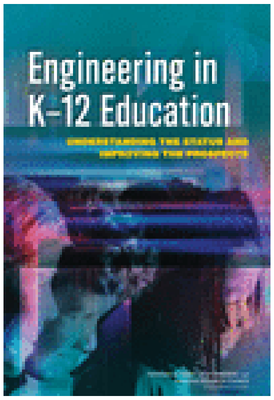

Engineering in K-12 Education: Understanding the Status and Improving the Prospects

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Introduction

In the past 15 years a consensus has emerged about the need to improve K–12 education, particularly in science, technology, engineering, and mathematics, the so-called STEM subjects. The lengthening list of groups and agencies calling for improvements includes the National Science Board, U.S. Department of Education, American Association for the Advancement of Science, National Academies, and many, many others (NSB, 2007; DOEd, 2008; AAAS, 1993; NAS, NAE, and IOM, 2007). In response, some legislative action, such as the 2007 America COMPETES Act (P.L. 110-69), has been taken to strengthen K–12 STEM education.

Many concerns about the quality of STEM education are related to the challenges facing the nation in an increasingly interconnected, increasingly competitive world. The general belief is that improving K–12 STEM education can help the country meet those challenges in two important ways. First, it will keep the "pipeline" of students prepared to pursue careers in various scientific and technical fields full. Second, it will raise the level of scientific and technological literacy in the general population. Ultimately, these changes should improve our ability to compete successfully in the global marketplace, defend ourselves against various non-economic threats, and improve our overall quality of life.

Based on those beliefs, a tremendous amount of attention has been paid to the question of how to improve the teaching and learning of science and mathematics in elementary and secondary schools. In fact, this has been the

focus of grants by federal agencies, presidential commissions, initiatives by professional organizations, and studies by think tanks. Improving technology education (the "T" in STEM), however, has received significantly less attention.

By contrast, almost no attention has been paid—at least on the national level—to the issue of engineering education (the "E" in STEM) in grades K–12. The goal of this report is to begin to fill that gap by providing an overview of the current state of K–12 engineering education in the United States and a discussion of what we must do in the coming years to make engineering a more effective component of the STEM equation.

CURRENT K–12 STEM EDUCATION

The STEM acronym is a relatively recent innovation (Cavanagh and Trotter, 2008). Until 2001, the common shorthand was SMET, science, mathematics, engineering, and technology. The National Science Foundation (NSF) was the first to begin referring to this collection of subjects as STEM, reflecting a change in philosophy. Up to that point, NSF's K–12 programs had targeted mostly high-achieving students who were the most likely to pursue careers in science, mathematics, and engineering. In the past decade, however, the agency has focused more resources on broad-based programs to appeal to the entire student population.

The STEM acronym has since become ubiquitous, which might lead one to conclude that the four subjects (Box 1-1) represent a well connected system of learning. However, in reality, in most elementary and secondary schools, STEM subjects are taught with little or no connection among them. Students learn mathematics in one classroom, science in another, and technology and engineering—if they learn them at all—in yet other classrooms.

Science and Mathematics

Science and mathematics are the two STEM components with the longest histories in K–12 education. Both subjects have standards, curricula, and assessments, large numbers of textbooks and other teaching materials, and established courses of teacher education and professional development. Every student in every school in the country is expected to have a minimum level of proficiency in science and mathematics by the end of high school.

More important in the context of this report, student proficiency in both science and mathematics is widely recognized as important to individual

BOX 1-1
The Four STEM Subjects*

Science is the study of the natural world, including the laws of nature associated with physics, chemistry, and biology and the treatment or application of facts, principles, concepts, or conventions associated with these disciplines. Science is both a body of knowledge that has been accumulated over time and a process—scientific inquiry—that generates new knowledge. Knowledge from science informs the engineering design process.

Technology comprises the entire system of people and organizations, knowledge, processes, and devices that go into creating and operating technological artifacts, as well as the artifacts themselves. Throughout history, humans have created technology to satisfy their wants and needs. Much of modern technology is a product of science and engineering, and technological tools are used in both fields.

Engineering is both a body of knowledge—about the design and creation of human-made products—and a process for solving problems. This process is design under constraint. One constraint in engineering design is the laws of nature, or science. Other constraints include such things as time, money, available materials, ergonomics, environmental regulations, manufacturability, and repairability. Engineering utilizes concepts in science and mathematics as well as technological tools.

Mathematics is the study of patterns and relationships among quantities, numbers, and shapes. Specific branches of mathematics include arithmetic, geometry, algebra, trigonometry, and calculus. Mathematics is used in science and in engineering.

*See Chapter 2 for a more detailed discussion of relationships among science, technology, engineering, and mathematics.

success and to the success of the country. Thus the relatively poor showing of U.S. students in these subjects on national assessments (Grigg et al., 2006; Lee et al., 2007) and comparative international studies, such as the TIMSS (Trends in International Mathematics and Science Study) assessment of fourth- and eighth-grade students around the world (Martin et al., 2008;

Mullis et al., 2008), has led to numerous calls for improving science and mathematics education.

In 2007, for example, the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (together called the National Academies) published *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. The purpose of the report was to determine how the United States could maintain its competitiveness in the global marketplace, and the first recommendation was to "increase America's talent pool by vastly improving K–12 mathematics and science education" (NAS, NAE, and IOM, 2007). A variety of legislative initiatives at the state and federal levels have also addressed the issue. In addition to the recently enacted America COMPETES Act, the No Child Left Behind Act of 2001 (P.L. 107-110) specifically targets student achievement in science and mathematics by, for example, mandating testing in both subjects and providing funding for math and science partnerships between school districts and local colleges and universities (DoEd, 2008).

Technology Education

Although technology education has roots in the manual and industrial arts, over the past two decades the field has broadened to emphasize understanding of technology in its most general sense (Box 1-2). Technology education today is the study of the human-made world, including artifacts, processes, and their underlying principles and concepts, and the overarching goal of technology education is to equip students to participate effectively in our technologically dependent world (e.g., NAE and NRC, 2002).

Some of the specific goals of technology education are described in *Standards for Technological Literacy: Content for the Study of Technology*, a report published in 2000 by the International Technology Education Association (ITEA). To meet those standards, K–12 students must develop competencies in five areas: the nature of technology, technology and society, design, abilities for a technological world, and the designed world. The fourth competency, "abilities for a technological world," requires that students know how to use and maintain everyday technologies and be able to assess the effects of using different technologies on society and the environment. The fifth competency, "the designed world," requires an understanding of technologies in specific areas, such as medicine, agriculture, and information and communications.

Despite a sustained campaign by ITEA and others, technology education is only slowly gaining acceptance. Many people—including many

BOX 1-2
A Broad View of Technology

In the broadest sense, technology is the process by which humans modify nature to meet their wants and needs. Most people, however, think of technology in terms of its artifacts: computers and software, aircraft, pesticides, water-treatment plants, birth-control pills, and microwave ovens, to name a few. But technology is more than these tangible products. The knowledge and processes used to create and to operate the artifacts—engineering know-how, manufacturing expertise, various technical skills, and so on—are equally important. Technology also includes all of the infrastructure necessary for the design, manufacture, operation, and repair of technological artifacts, from corporate headquarters and engineering schools to manufacturing plants and maintenance facilities. Technology is a product of engineering and science, and science and technology are tightly coupled. A scientific understanding of the natural world is the basis for much of technological development today. Conversely, technology is the basis for a good part of scientific research. The climate models meteorologists use to study global warming, for example, require supercomputers to run the simulations. Technology is also closely associated with innovation, the transformation of ideas into new and useful products or processes. Innovation requires not only creative people and organizations, but also the availability of technology and science and engineering talent. Technology and innovation are synergistic. The development of gene-sequencing machines, for example, has made the decoding of the human genome possible, and that knowledge is fueling a revolution in diagnostic, therapeutic, and other biomedical innovations.

SOURCE: Adapted from NAE and NRC, 2002.

educators—confuse it with classes that train students to use computers. Today, classes in technology education are offered in a minority of school districts around the country, and only 12 states require completion of a technology education course by students graduating high school (Dugger, 2007). Consequently, there are far fewer technology education teachers working in U.S. schools than science or mathematics teachers, and far fewer students taking technology education classes than classes in science and mathematics. Finally, technology education has received very little attention from policy makers. Compared to science and mathematics, technology is still a small blip on the radar screen of STEM education.

Engineering

If technology education is a small blip on the STEM radar screen, engineering education is almost invisible. Few people even think of engineering as a K–12 subject, and nationwide, very few K–12 teachers are engaged in engineering education, and very few schools expose students to engineering ideas and activities. Engineering curricula that have been developed vary widely in focus, content, and requirements for implementation. Their purposes range from encouraging students to pursue careers in engineering to increasing technological literacy and improving student performance in science and mathematics. The conceptual frameworks of these curricula also vary greatly. No standards have been set for engineering education, no state or national assessment has been adopted, and almost no attention has been paid to engineering education by policy makers. In fact, engineering might be called the missing letter in STEM.

Connection among the STEM Subjects

Most K–12 schools in the United States teach STEM subjects as separate disciplines, sometimes called "silos"—a math silo, a science silo, perhaps a technology education silo, and, in rare cases, an engineering silo—with few connections in curriculum, in teaching, or in classroom activities. Thus opportunities for leveraging the benefits of interconnections, such as using science inquiry to support learning of mathematical concepts, are largely lost. Students are left with an implicit message that each discipline stands on its own.

This is a stark contrast to the real world of research and technology development, where scientists, engineers, mathematicians, and technologists—along with social scientists, business managers, and others—work together in teams to solve problems. Each STEM discipline brings unique capabilities and perspectives, but for the team to function effectively, each player must be able to draw on and use knowledge from all four disciplines. In some cutting-edge areas, such as nanotechnology, the line between scientists and engineers has all but disappeared.

Opportunity and Uncertainty

The near absence of engineering education in K–12 classrooms represents both opportunity and uncertainty. The opportunity lies in strengthening the engineering component of STEM education, which data presented

in Chapter 3 suggest can simultaneously complement and improve learning in the other three disciplines. The uncertainty arises because there are still a great many unanswered questions about how engineering education should be incorporated into K–12 classrooms, as well as about the value of existing K–12 engineering education.

THE STUDY AND REPORT

The purpose of this study is to address three specific questions:[1]

- What are realistic and appropriate learning outcomes for K–12 engineering education?
- How might engineering education complement the learning objectives of other content areas, particularly science, technology, and mathematics, and how might these other content areas complement learning objectives in engineering education?
- What educational policies, programs, and practices at the local, state, and federal levels might lead to the meaningful inclusion of engineering in K–12 education in the United States?

The Study Committee

To answer these questions, in 2006 the National Academy of Engineering (NAE) and National Research Council Center for Education established the Committee on K–12 Engineering Education. The work of the committee was supported by a grant from NAE member Stephen D. Bechtel, Jr., and additional funds were provided by the Parametric Technology Corporation and NSF.

Study Objectives

The study had four objectives:

- Survey the landscape of current and past efforts to implement engineering-related K–12 instructional materials and curricula in the United States and other nations.

[1]The complete statement of task appears in an annex to this chapter.

- Review the available information showing the impact of these initiatives.
- Describe how K–12 engineering content incorporates science, technology, and mathematics concepts, uses these subjects as context for exploring engineering concepts, or uses engineering as a context for exploring science, technology, and mathematics concepts.
- Report on the intended learning outcomes of K–12 engineering education initiatives, taking into account the age of the students, the focus of the curriculum (e.g., science vs. technology education), the orientation of the program (e.g., general education vs. career/vocational education), and other factors.

Although efforts have been made to introduce engineering to K–12 students in a variety of informal (non-school) settings, through websites, contests, after-school programs, and summer programs, this study focused only on formal K–12 activities.

Fact-Finding Process

To meet these objectives and answer the questions listed above, the committee spent two years studying K–12 engineering education in the United States. During this time, the committee held five face-to-face meetings, two of which accompanied information-gathering workshops.

To get a sense of the K–12 engineering "landscape," the committee commissioned an analysis of existing K–12 engineering curricula and reviews of the literature on conceptual learning related to engineering, the development of engineering skills, and evidence of the effectiveness of K–12 engineering education initiatives. Finally, the committee also collected preliminary information about a few pre-college engineering education efforts in other countries.

This report is based on these meetings, workshops, and analyses and reviews, as well as the expertise and experience of committee members.

Report Outline

Chapter 2 of the report addresses the question, "What is engineering?" Although many readers already have a clear idea of engineering, the committee believes that understanding the purposes of and approaches to K–12 engineering education requires understanding not only what engineering

is but also the key concepts of engineering (e.g., optimization, systems, the design process) and the relationships between engineering and other disciplines, particularly science and mathematics.

Chapter 3 provides a discussion of the available evidence showing the benefits of K–12 engineering education, such as improving learning in mathematics and science, improving technological literacy, and encouraging young people to consider careers in engineering or other technical fields, and the challenges to teaching engineering to K–12 students. Chapter 4 includes reviews of current K–12 engineering curricula, based largely on the commissioned analyses and reviews. In addition, the chapter reviews teacher education and professional development programs.

Chapter 5 discusses cognitive science research related to how students learn engineering concepts and skills and what this research suggests about the best approaches to teaching engineering in grades K–12. The committee's findings and recommendations are presented in Chapter 6.

Appendix A of the report provides biographical information for committee members; Appendix B contains short descriptive summaries of 19 curriculum projects that did not receive a detailed review by the committee; Appendix C, included on an accompanying CD inside the back cover of the report, contains detailed reviews of another 15 K–12 engineering education curriculum projects.

Intended Audiences

This report will be of special interest to individuals and groups interested in improving the quality of K–12 STEM education in this country. But engineering educators, policy makers, employers, and others concerned about the development of the country's technical workforce will also find much to ponder. The report should prove useful to advocates for greater public understanding of engineering, as well as to those working to boost citizens' technological and scientific literacy. Finally, for educational researchers and cognitive scientists, the document exposes a rich set of questions related to how and under what conditions students come to understand engineering.

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Annex

PROJECT STATEMENT OF TASK

The goal of this project, a collaboration between the National Academy of Engineering and the National Research Council's Center for Education,

through its Board on Science Education, is to provide carefully reasoned guidance to key stakeholders regarding the creation and implementation of K–12 engineering curricula and instructional practices, focusing especially on the connections among science, technology, engineering, and mathematics education.

Engineering is defined as "design under constraint," where the constraints include the laws of nature, cost, safety, reliability, environmental impact, manufacturability, and many other factors. While science attempts to discover what is, engineering is concerned with what might be—with extending human capability through modifying the natural world. Indeed, engineering is responsible for many of the most significant improvements in our quality of life. Engineers identify and then solve problems using a highly creative and iterative design process. While engineering requires the application of mathematics and scientific knowledge, it is this design process and the practical nature of the problems tackled that best distinguish engineering. What qualifies as engineering in the K–12 classroom, as contrasted with what engineering education is in post-secondary institutions, is something that this project will attempt to elucidate. In the early grades, "engineering" may be little more than a teacher-directed design activity, such as the construction of a balsa wood bridge, while in the later grades the design project may be considerably more open ended and involve the application of mathematics and science concepts to solve a specific problem.

The project has the following objectives:

1. Survey the landscape of current and past efforts to implement engineering-related K–12 instructional materials and curricula in the United States and other nations.
2. Review evidence related to the impact of these initiatives, to the extent such information is available;
3. Describe the ways in which K–12 engineering content has incorporated science, technology, and mathematics concepts, used these subjects as context to explore engineering concepts, or used engineering as a context to explore science, technology, and mathematics concepts; and
4. Report on the intended learning outcomes of K–12 engineering education initiatives, taking into account student age, curriculum focus (e.g., science vs. technology education), program orientation

(e.g., general education vs. career/vocational education), and other factors.

In meeting the goal and objectives, the project will focus on three key issues and three related guiding questions:

1. There are multiple perspectives about the purpose and place of engineering in the K–12 classroom. These points of view lead to emphases on very different outcomes. QUESTION: What are realistic and appropriate learning outcomes for engineering education in K–12?
2. There has not been a careful analysis of engineering education within a K–12 environment that looks at possible subject intersections. QUESTION: How might engineering education complement the learning objectives of other content areas, particularly science, technology, and mathematics, and how might these other content areas complement learning objectives in engineering education?
3. There has been little if any serious consideration of the systemic changes in the U.S. education system that might be required to enhance K–12 engineering education. QUESTION: What educational policies, programs, and practice at the local, state, and federal levels might permit meaningful inclusion of engineering at the K–12 level in the United States?

Prior to the stage when the committee completes the preparation of its draft report for the institutional report review process, the committee will strive to obtain public inputs on key issues and on directions for the committee to consider in its recommendations.